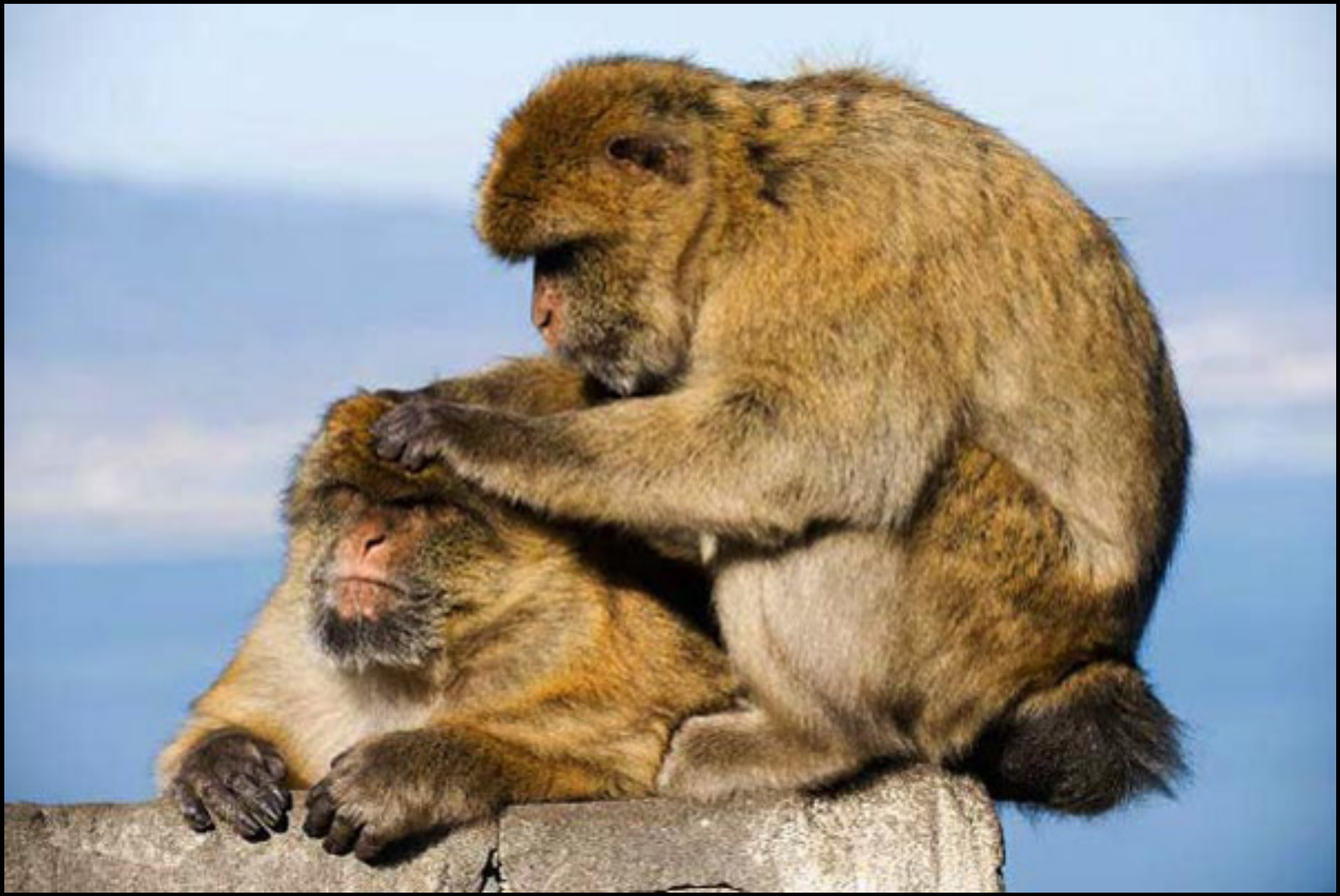
Future Perspectives on STAR Exotic Searches



Aihong Tang for the STAR Collaboration

Outline

- Advantages of RHIC/STAR.
- STAR's exotic search programs.
- Summary.

RHIC is Flexible

C.M. Energy per nucleon pair (GeV)	Collision Species
500	Polarized p+p
200	Polarized p+p, Au+Au, d+Au, Cu+Cu
130	Au+Au
62.4	Polarized p+p, Au+Au, Cu+Cu
39	Au+Au
19.6—22.4	Au+Au, Cu+Cu
11	Au+Au
7.7	Au+Au
9.2	Au+Au test
200	U+U and/or Cu+Au (2012)

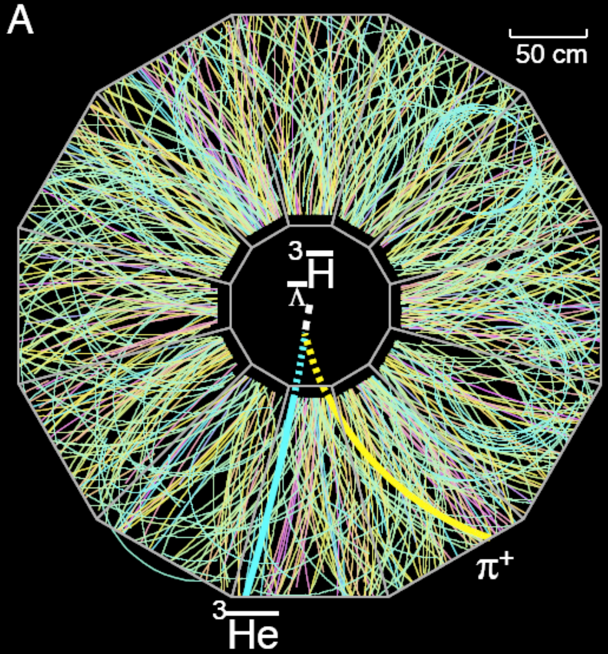
RHIC is Bright

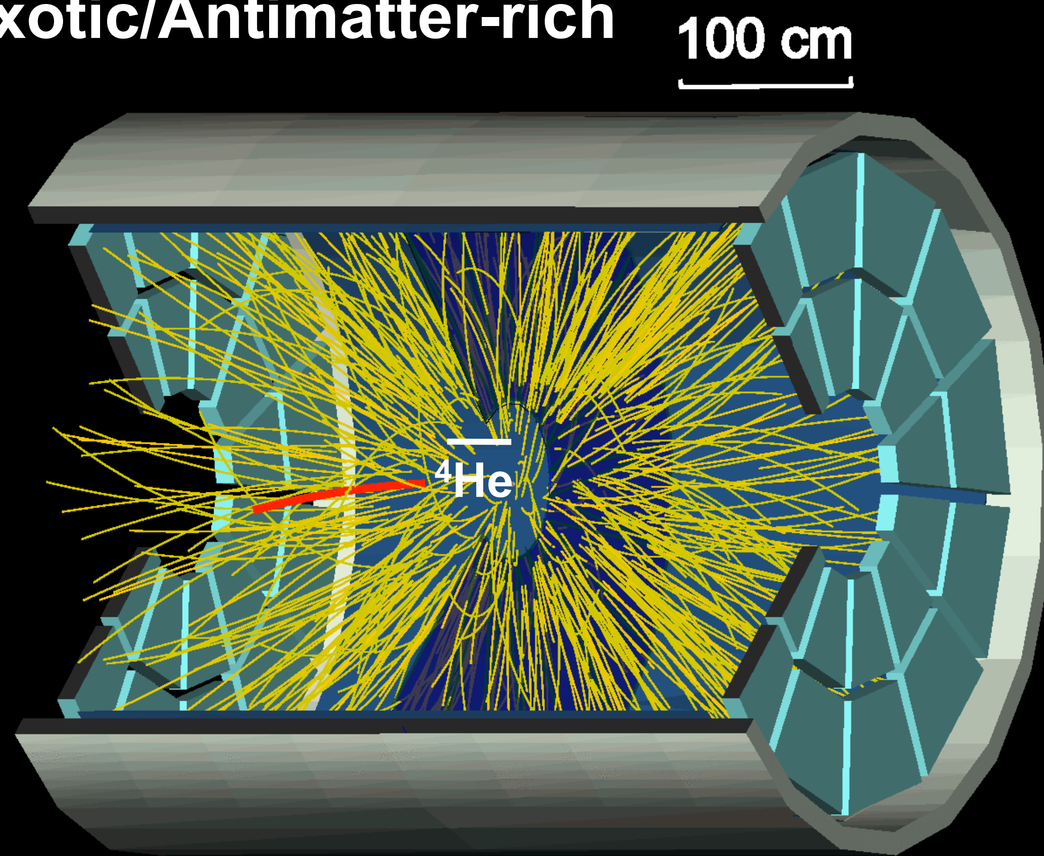
- Annual Au+Au collisions to tape : STAR : ~1 billion; PHENIX: ~10 billion.

- Luminosity p+p equivalent: possibly up to fb^{-1}.

- Annual particles to tape: > 10^{12}.

RHIC is Exotic/Antimatter-rich





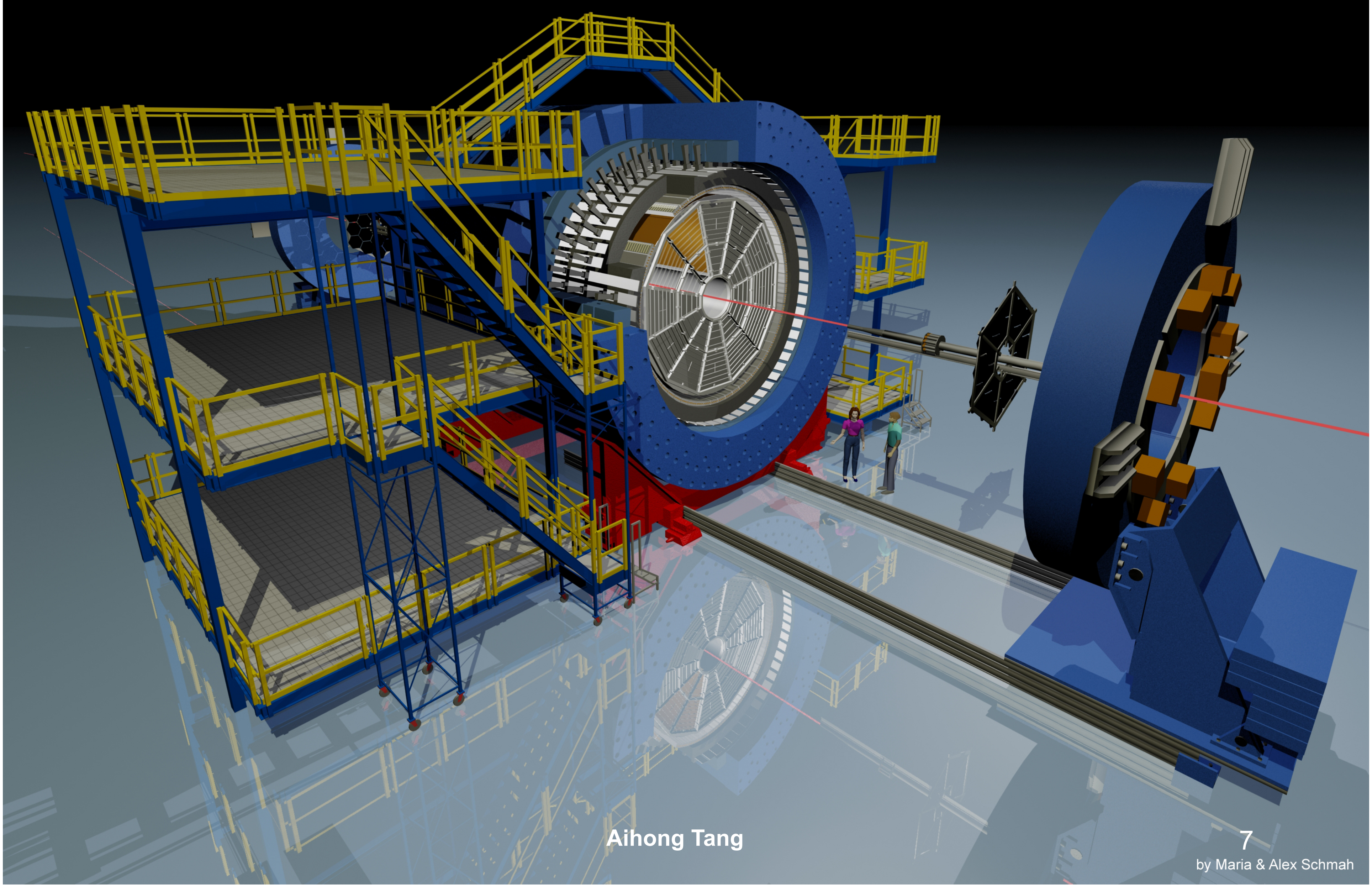
***Science* 328,** 58 (2010)

***Nature* 473,** 353 (2011)

AntiHelimum discovery made into top 100 stories of 2011 :

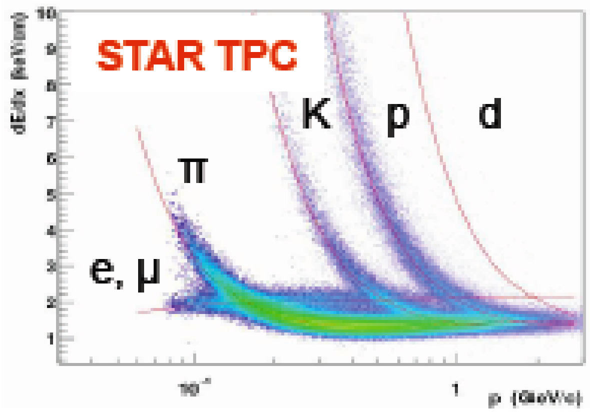
#20 in all disciplines, #3 in Physics.

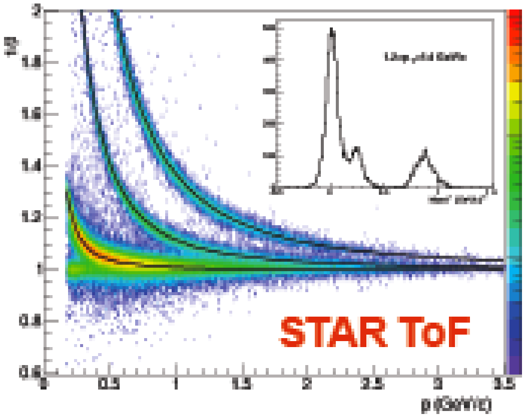
STAR : Uniform and Large Acceptance

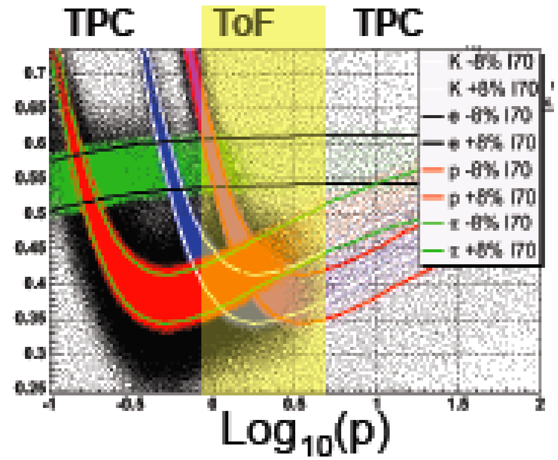


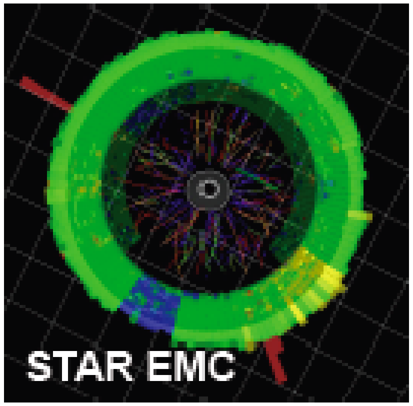
by Maria & Alex Schmah

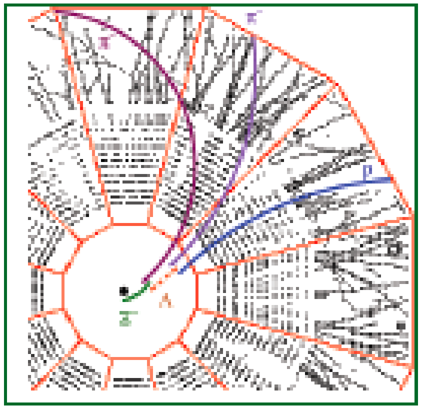
STAR : Excellent PID and Tracking

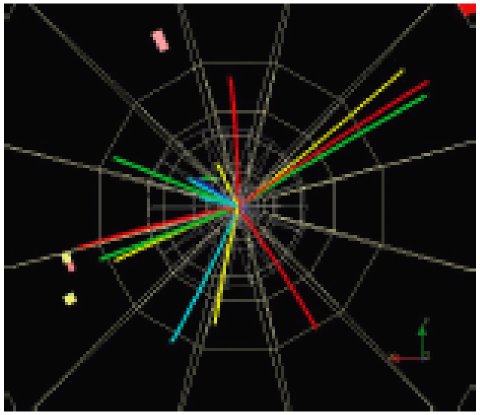


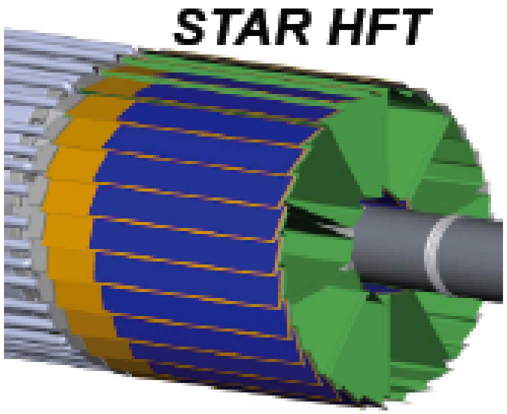








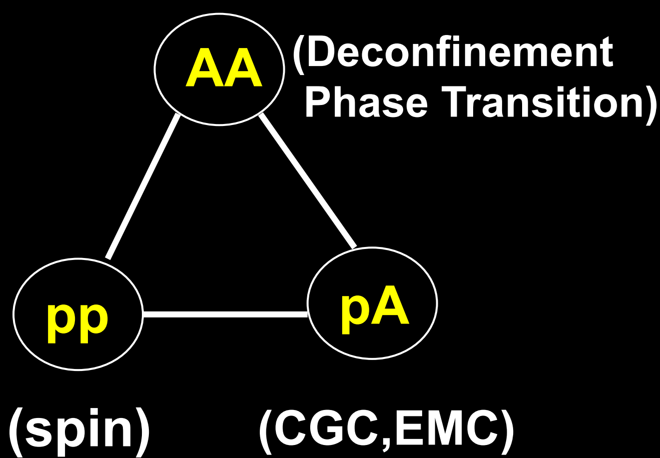


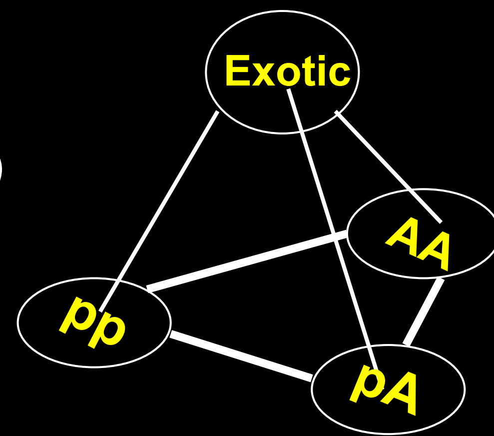


Neutral particles **Strange hyperons** **Jets** **Heavy Quark Hadrons**

Exotic/Rare Phenomena at RHIC

RHIC : QCD Machine & Beyond





Courtesy of H. Huang

A New Dimension to RHIC Physics

Exotic/Rare Particle Search in STAR

Push the boundary of Standard Model
- Dibaryon at midrapidity
- Strangelet search at forward region

Look for new physics beyond Standard Model
- Rare decays
- Antimatter

Atom/parton chemistry test ground
- Atomcules
- Muonic Atoms
- Glueball

Extension and beyond RHIC-II
- Potentials at EIC

The H^0-Dibaryon

Strangelet

6 quark-bag bound state (uuddss)

$mH^0 < 2m_\Lambda = 2231$ MeV

Stable against strong decay but not against weak hadronic decay

$\tau = 10^{-8}$-10^{-10} s

(R. Jaffe PRL 38 195 (1977), Donoghue'86 …)

Decay mode :

	$N\Sigma$	$\Lambda N\pi$
Mass threshold (MeV)	2134	2192	2231

Hadronic Counterpart

$(\Lambda\Lambda)_b$

Other dibaryons might exist as bound states made by coalescence of 2 strange baryons

(Schaffner-Bielich et al PRL 84 (2000) …)

Decay length ~ 1-5cm

$(\Lambda\Lambda)_b \rightarrow \Lambda + p + \pi$ } $dN/dy \sim 10^{-2}$-10^{-3}/event

$\rightarrow \Sigma^- + p$

$(\Sigma^+ p)_b \rightarrow p + p$

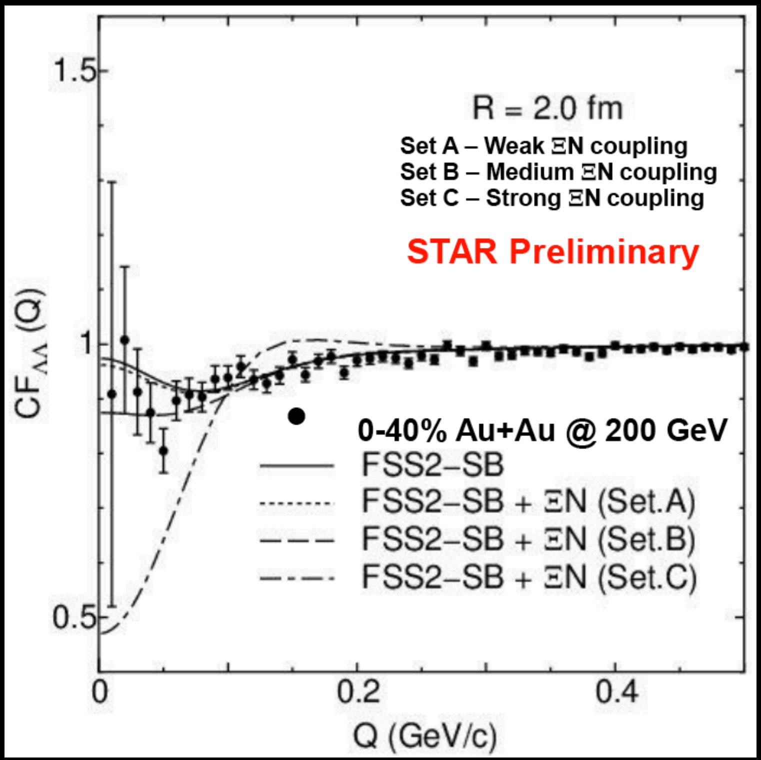
$(\Xi^0 p)_b \rightarrow \Lambda + p$

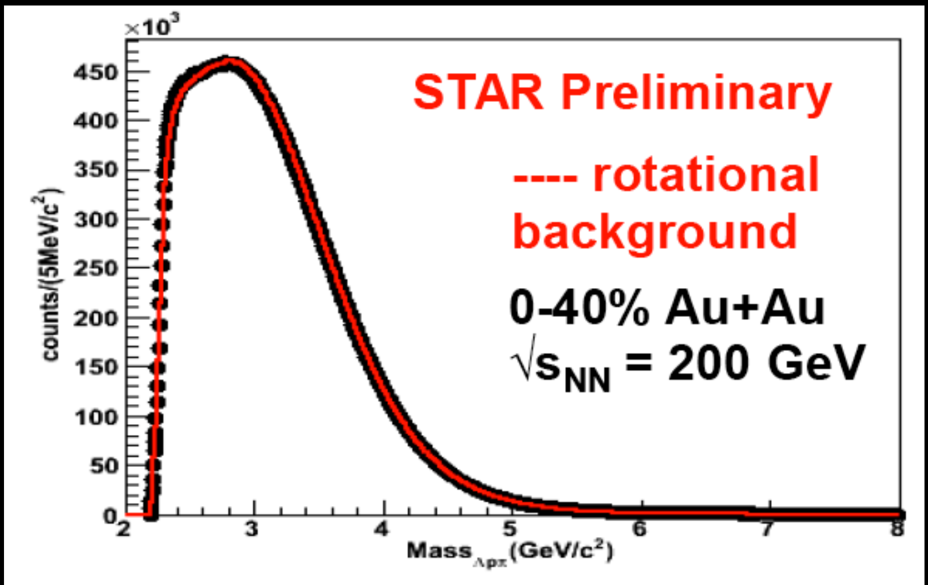
$(\Xi^0 \Lambda)_b \rightarrow \Lambda + \Lambda$

$\rightarrow \Xi^- + p$

} $dN/dy \sim 10^{-3}$/event

The H^0-Dibaryon

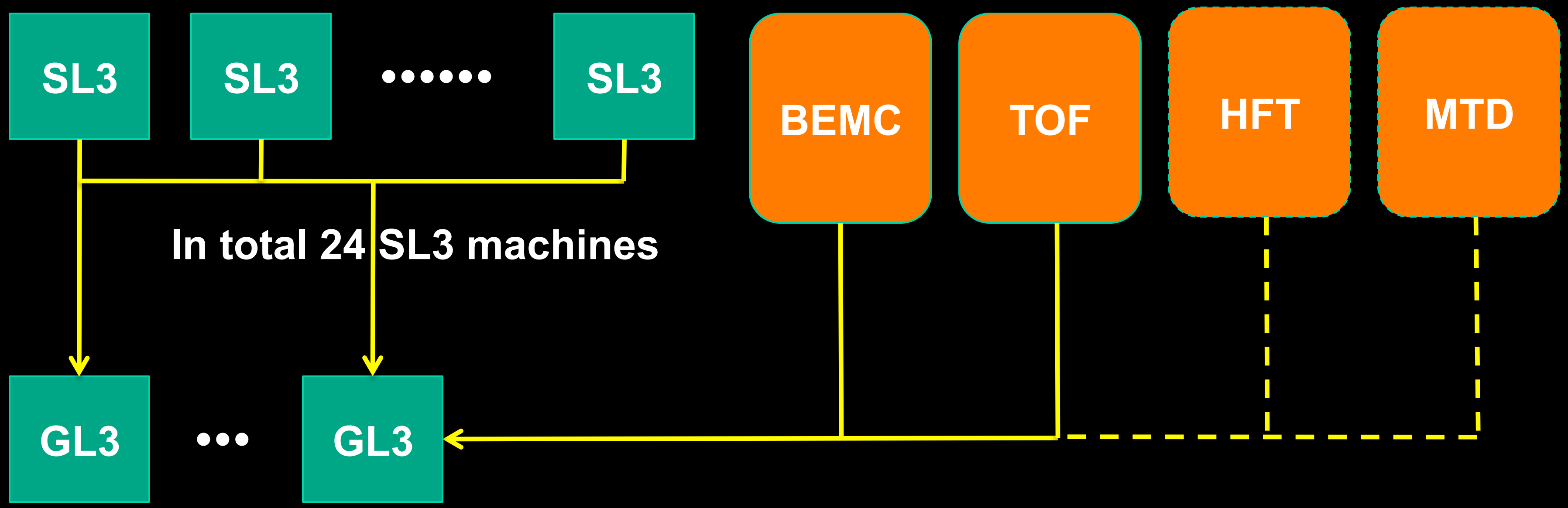




N. Shah (for the STAR Collaboration), this workshop

Active ongoing effort

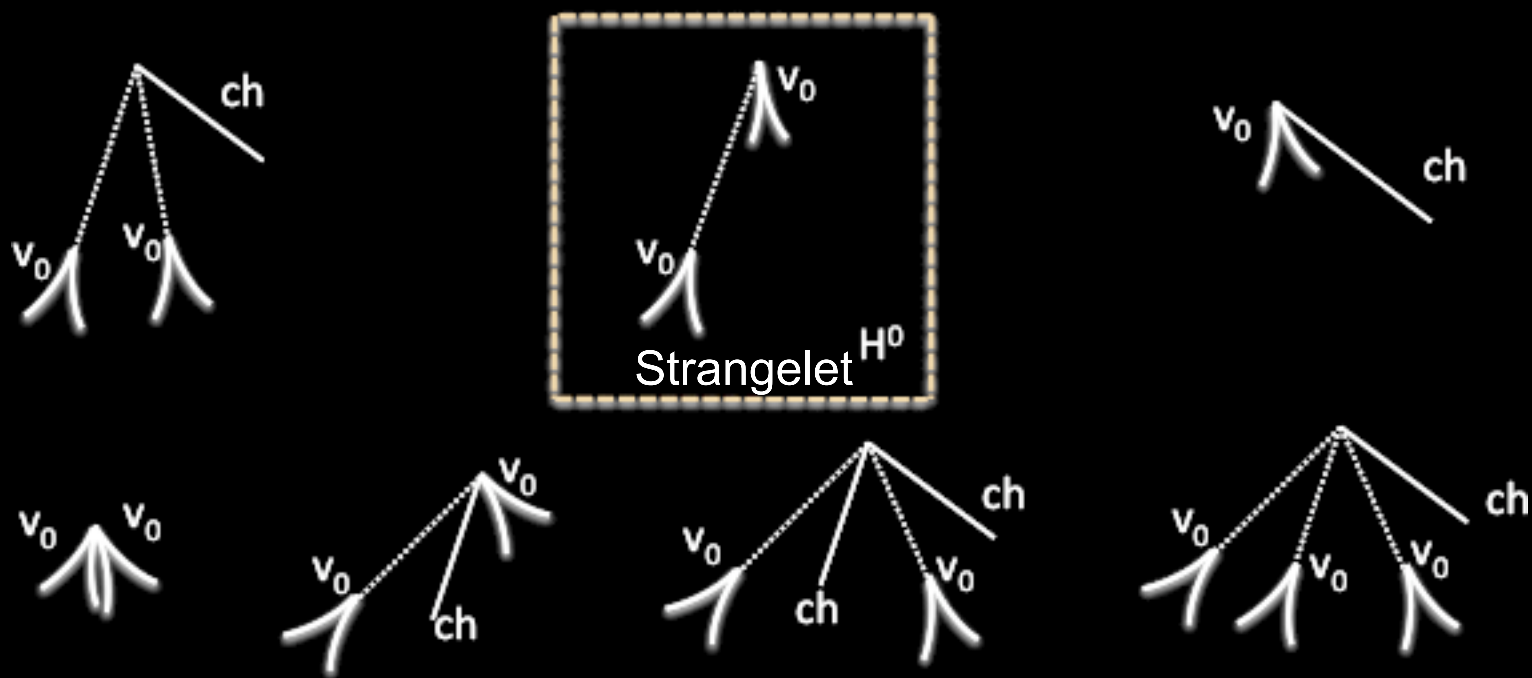
The H^0-Dibaryon : HLT as trigger



- Sector tracking (SL3) in DAQ machines (24 in total, each for a TPC sector).
- Information from subsystems (SL3 and others) are sent to Global L3 machines (GL3) where an event is assembled and a trigger decision is made.

Online Event tagger/trigger
Fast physics output with HLT

The H^0-Dibaryon : How to trigger

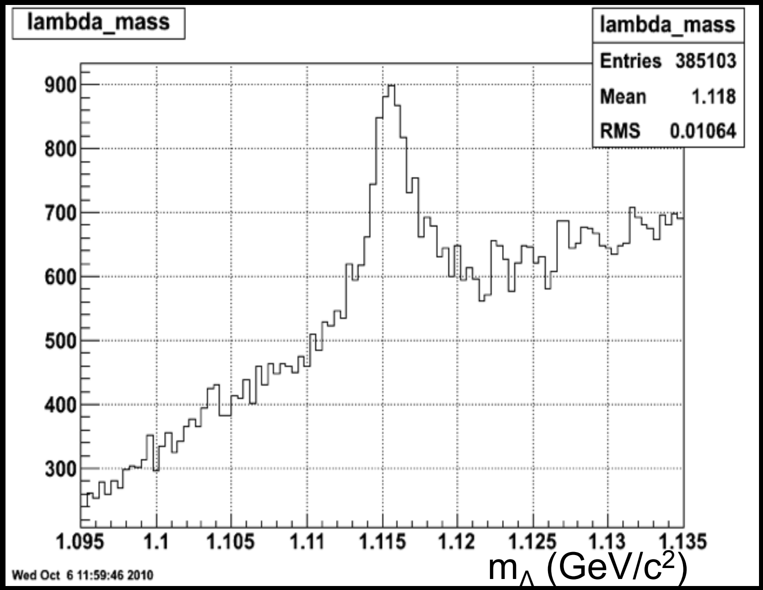


Trigger on secondary decay topologies (with GPU acceleration) → potential for new discoveries

The H^0-Dibaryon Reconstruction : GPU acceleration

Test result :
GPU (Nvidia GTX280) vs CPU (Intel 2.8 G)

	CPU	GPU (GeForce GTX 280)
clock	2.80GHz	1.3GHz
Time cost	93us/pair	1.3us/pair

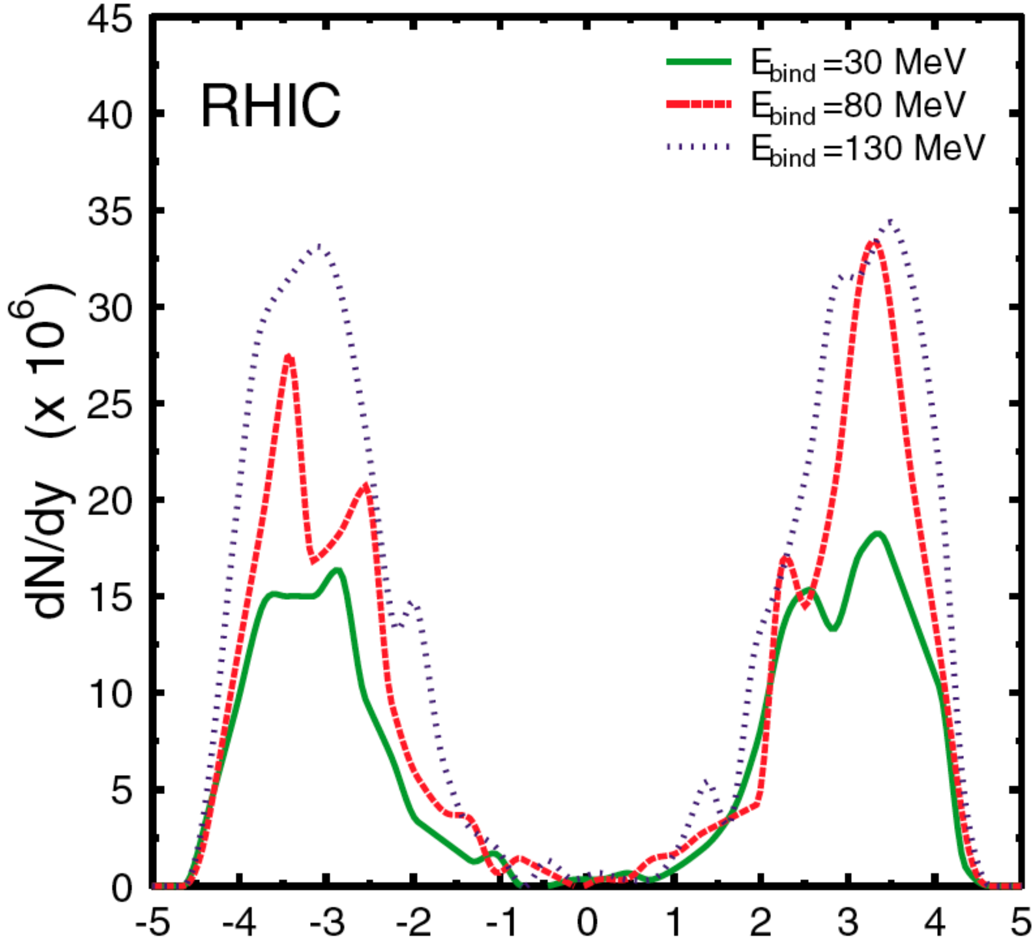


GPU is 60 times faster than single CPU Core considering data transmission.

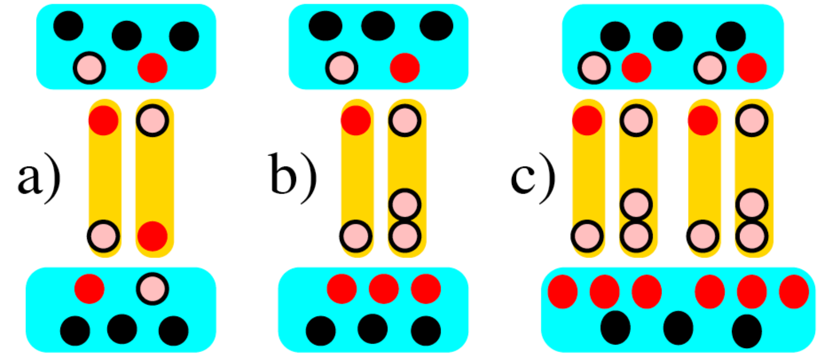
Lambda reconstructed by GPU (real data from run10 AuAu 200GeV, HLT tracks).

GPU significantly accelerates v_0 reconstruction
R&D ongoing. Seeking funding.

Strangelet Search in Forward Region



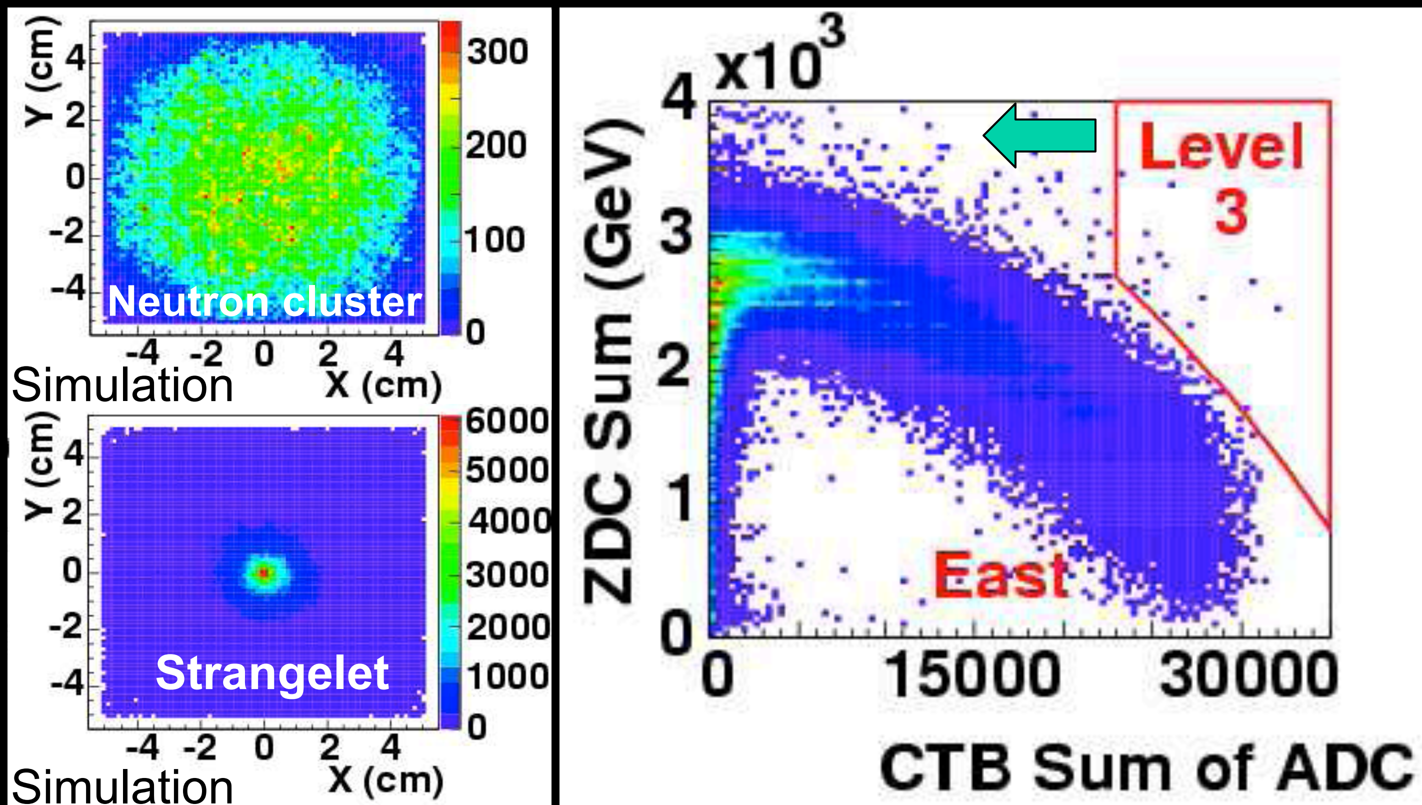
Bleicher et al., Phys. Rev. Lett. 92, 072301 (2004)



Strangelet formed in remnants by compensating the flavor change due to pomeron breaking.

Peaked in beam directions

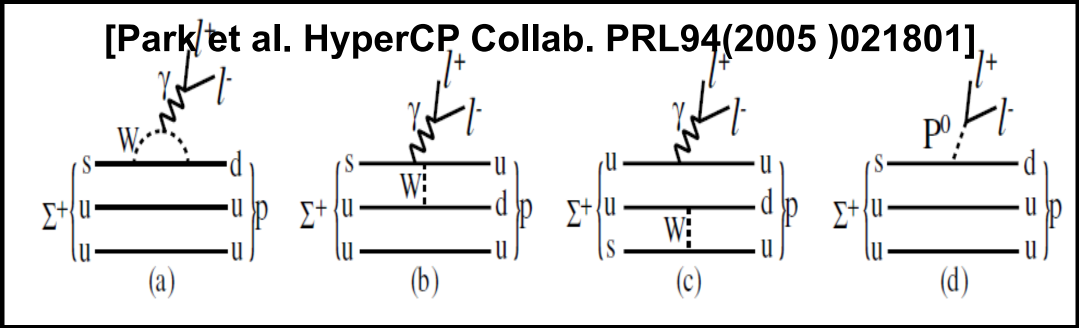
Strangelet Search in Forward Region

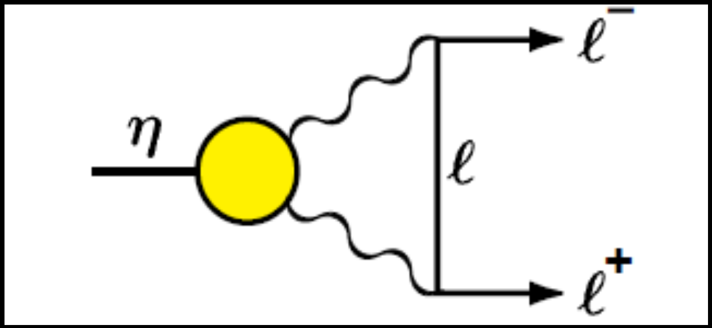


STAR, PRC 76, 011901 (2007)

Revisit the strangelet search in forward region by moving away from central collisions.

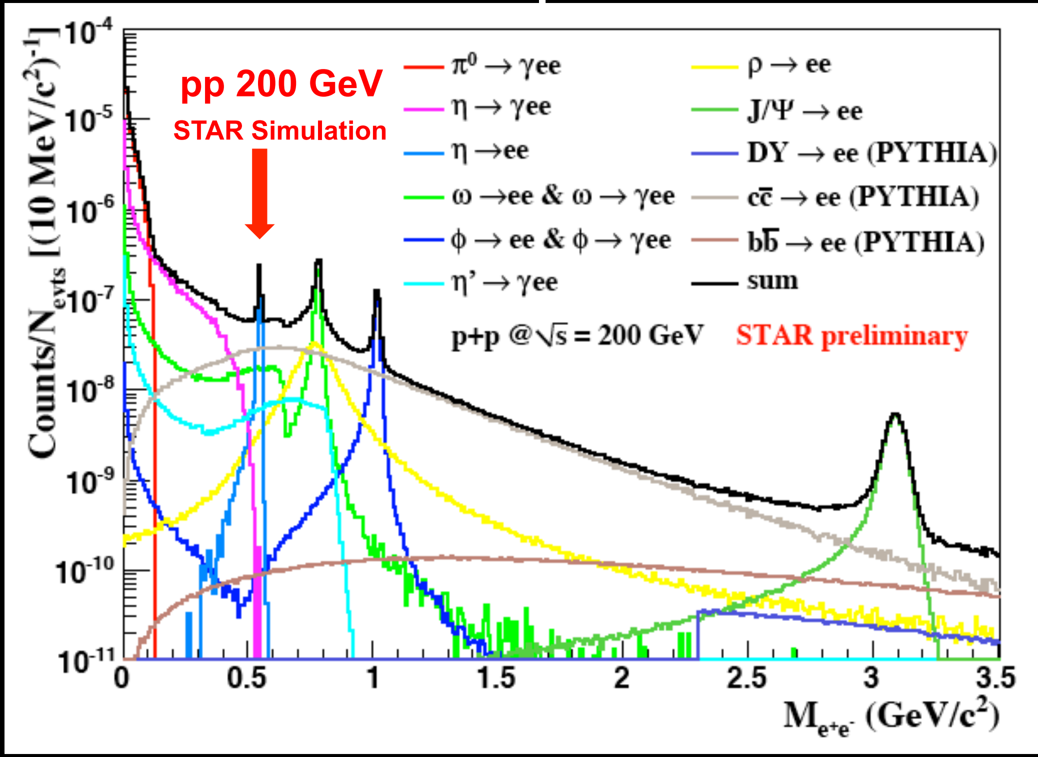
Rare Decays





$\Sigma \rightarrow p l^+ l^-$

$\eta \rightarrow l^+ l^-$

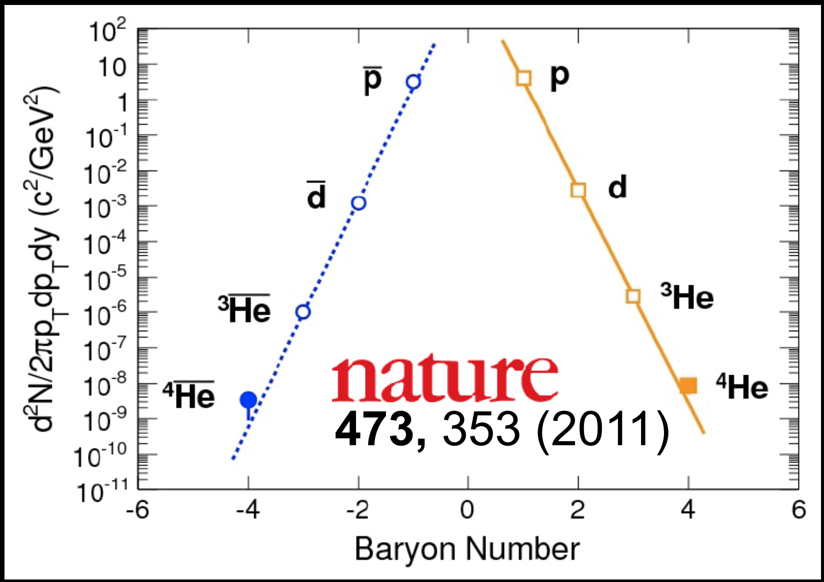


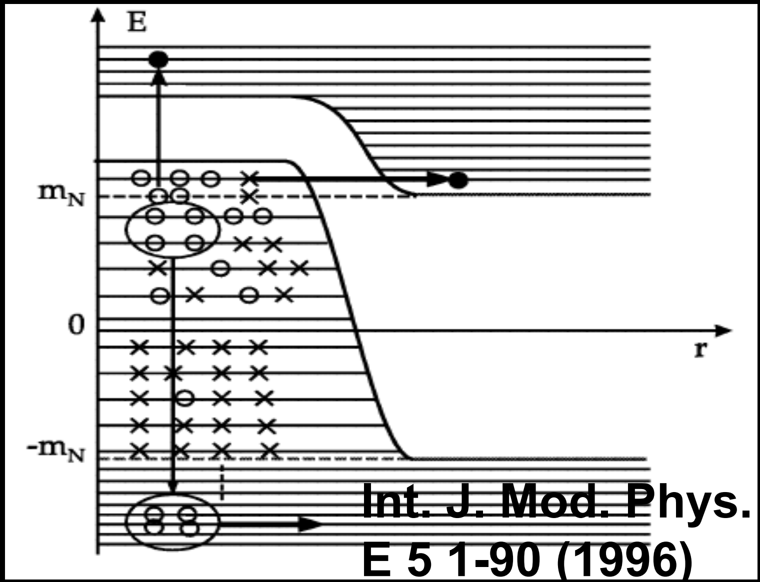
Search for traces of New Physics beyond the standard model.

These decays usually involve EM or weak coupling which can calculated to high accuracy.

STAR has high rate capability and excellent lepton ID at low momentum.

Antimatter





Idea from Walter Greiner: correlations are present in vacuum, allowing antinucleus like anti-α to be directly excited from the vacuum. Rate could be much larger than low value predicted by statistical coalescence.

No evidence but we should watch for it.

Antimatter

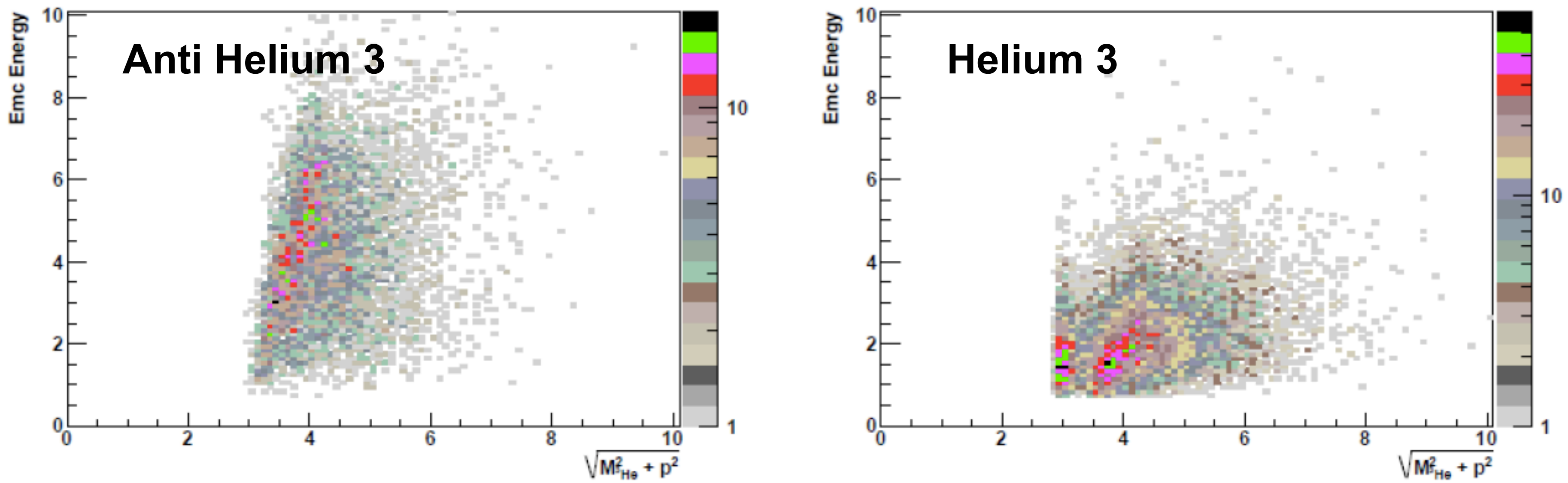
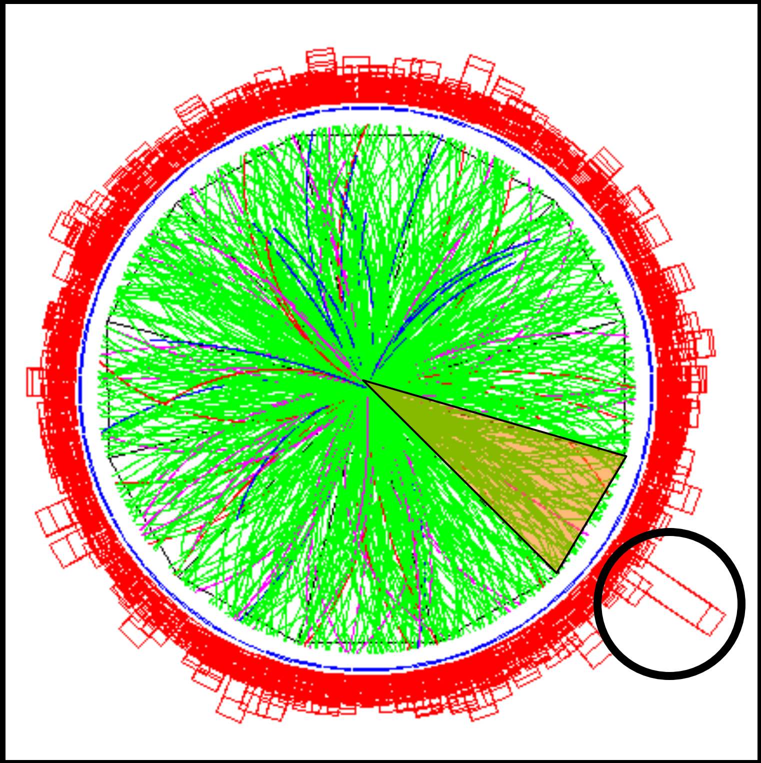


Figure 2.52: Left panel: $^3\overline{He}$ EMC energy vs TPC $\sqrt{m^2 + p^2}$. Right panel: same for ^3He.

Trigger on antimatter with BEMC

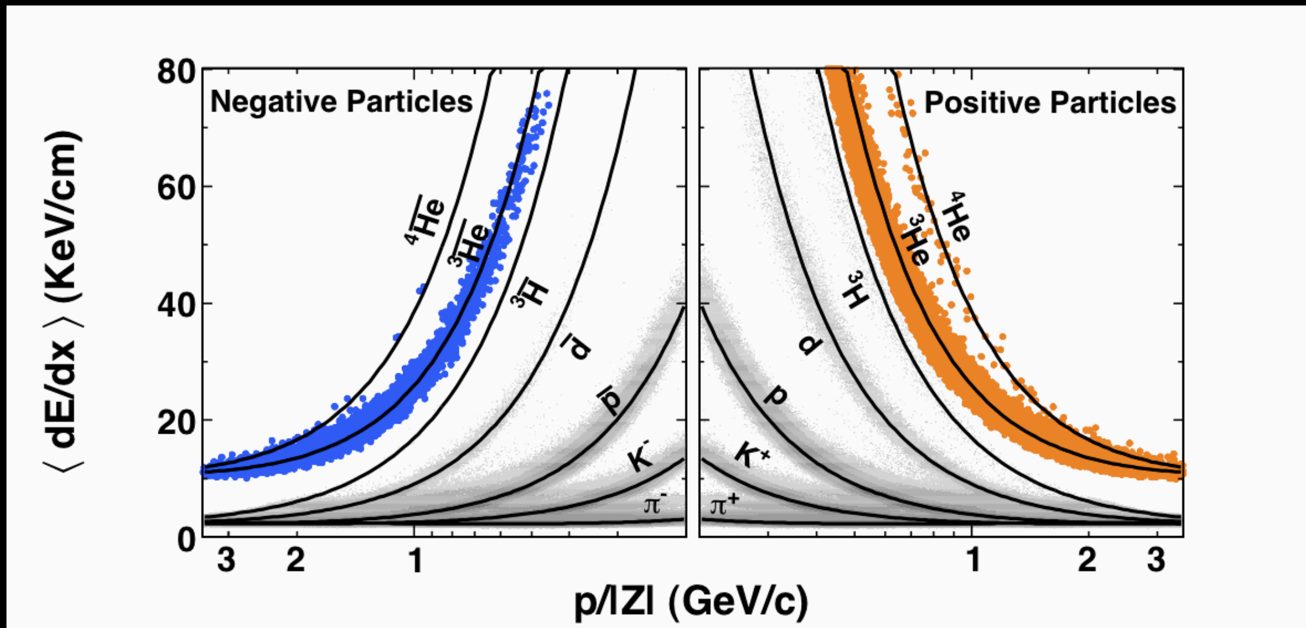
Look for possible heavier antimatter and enrich samples for (anti)hypernuclei studies.

Antimatter



DAQ 10K, readout a TPC sector of interest only
Significantly increase DAQ speed.

Benefit from Anti(nuclei)-rich environment



A = 4, or 5 unstable (anti)nuclei :

$^4\overline{\text{He}}^* \rightarrow \overline{\text{t}} + \overline{\text{p}}$

$^4\overline{\text{Li}} \rightarrow {}^3\overline{\text{He}} + \overline{\text{p}}$

$^5\overline{\text{Li}} \rightarrow {}^4\overline{\text{He}} + \overline{\text{p}}$

S = 2 or 3 (anti)hypertriton :

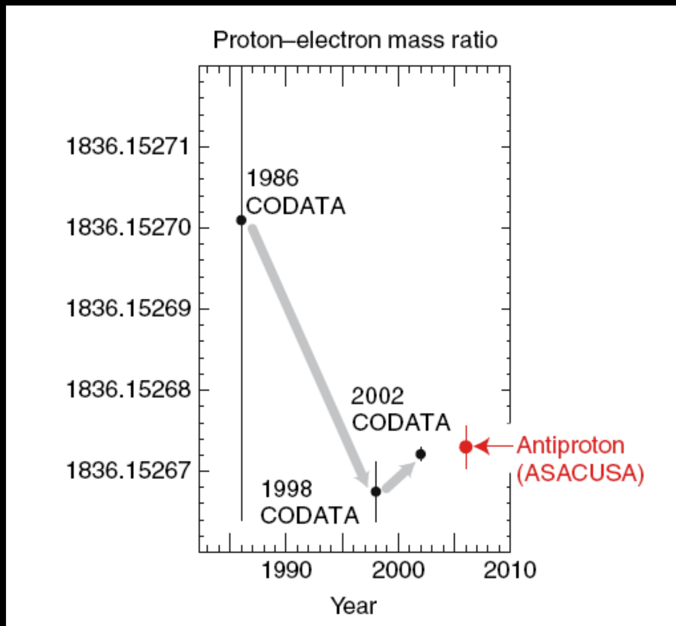
$\text{pn}\Xi^- \rightarrow \pi^- + \pi^- + {}^3\text{He}$

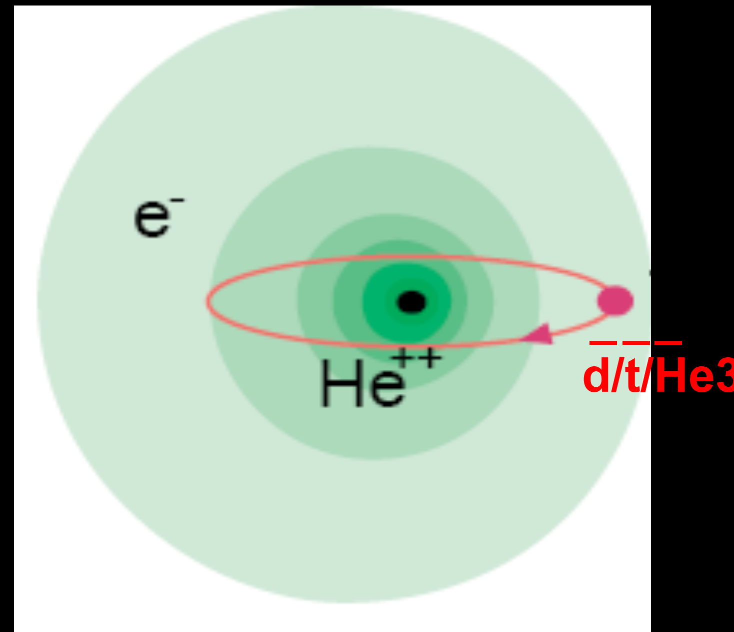
$\text{pn}\Omega^- \rightarrow \pi^- + \text{k}^- + {}^3\text{He}$

……

Rich light (anti)nuclei environment offers new opportunities

Creating First Antinucleus Atomcules





Metastable antiproton-helium atom discovered at KEK: Iwasaki, PRL 67 (1991); nature 361 (1993) 238
Mass difference: p-pbar < 2×10^{-9}; Hori, PRL 96 (2006);
measurement of baryon mass and magnetic moment for CPT test at LEAR/CERN
http://asacusa.web.cern.ch/ASACUSA/index-e.html

What if we replace antiproton with antiDeuteron, antiTriton or antiHelium3 ?
Only RHIC can address this question with enough antimatter nuclei.
Measure Antinucleus mass (CPT test)
Antinucleus-nucleus annihilation

Muon Atoms

PHYSICAL REVIEW D VOLUME 48, NUMBER 9

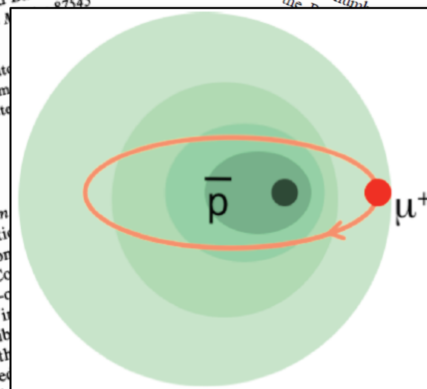
Production of muon-meson atoms in ultrarelativistic heavy-ion collisio

Gordon Baym,* Gerald Friedman, R. J. Hughes, and Barbara V. Jacak

PHYSICAL REVIEW C VOLUME 59, NUMBER 5 MAY 1999

Hydrogenlike atoms from ultrarelativistic nuclear collisions

Joseph Kapusta* and Agnes Mocsy†



PHYSICAL REVIEW LETTERS 19 APRIL 1982

Measurement of the Rate of Formation of Pi-Mu Atoms in K_L^0 Decay

Aronson, R. H. Bernstein, G. J. Bock, R. D. Cousins, Jr.,[a] J. F. Greenhalgh,[b] D. Hedin,[c] M. Schwartz, T. K. Shea, G. B. Thomson,[d] B. Winstein

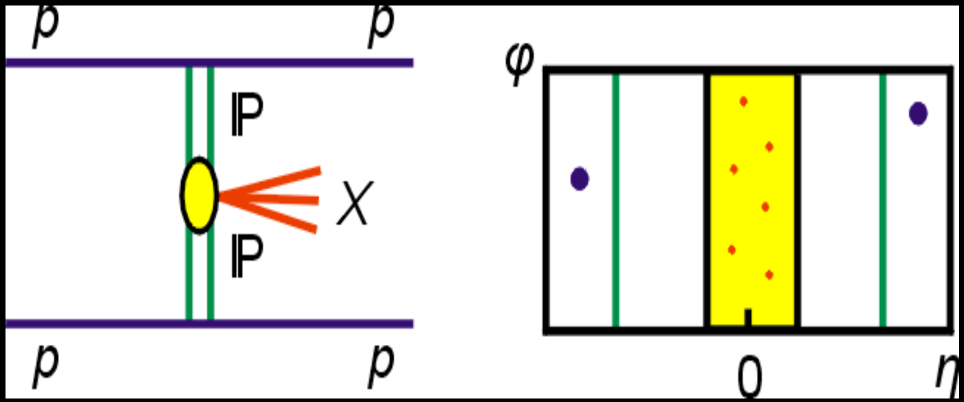
(Received 5 February 1982)

Hydrogenlike atoms consisting of a pion and a muon can be formed in $K_L^0 \to \pi\mu\nu$ decays. In an intense, high-energy K_L^0 beam, 320 pi-mu atoms were detected and simultaneously the K_L^0 flux was monitored by recording ordinary $K_L^0 \to \pi\mu\nu$ decays. The first measurement is reported of the branching ratio $R = \Gamma(K_L^0 \to \text{pi-mu atom} + \nu)/\Gamma(K_L^0 \to \pi\mu\nu) = (3.88 \pm 0.41) \times 10^{-7}$, using a subset of 155 atoms. This ratio may be sensitive to anomalous interactions between the pion and the muon. In the absence of such interactions, theory predicts $R = (4.43 \pm 0.12) \times 10^{-7}$.

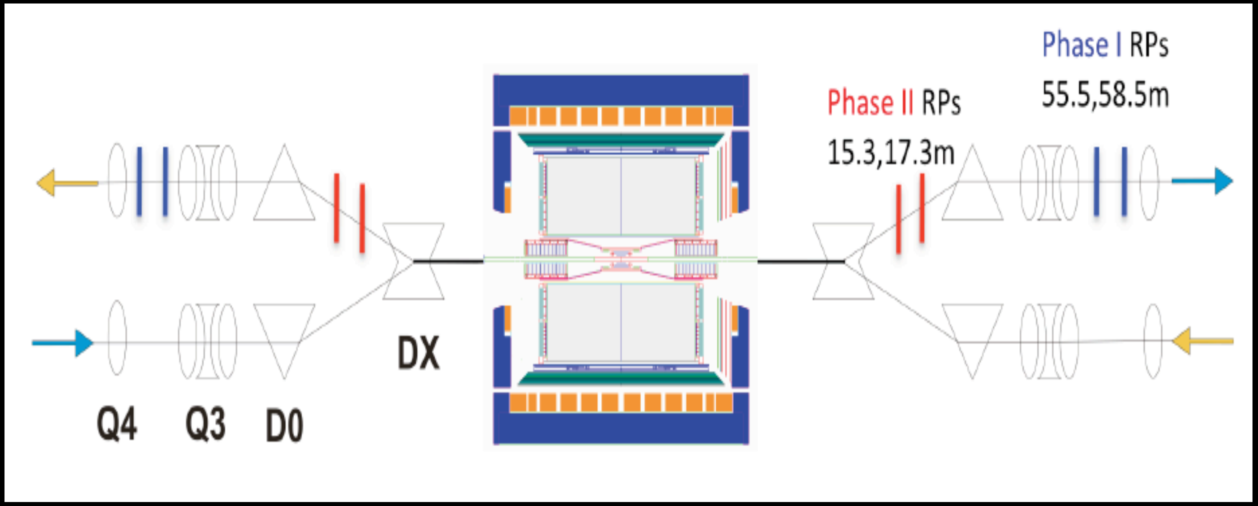
PACS numbers: 13.20.Eb, 13.60.-r, 14.40.Aq, 36.10.-k

Exciting new possibilities: Muon Hydrogen-like atoms, Muon-meson Atoms.
Direct measure of single lepton spectrum from thermal radiation.
Large TOF signal with dissociation at beam structure.

Glueball Search with Roman Pots
Phase II pp2pp at STAR



pp ➔ pM_Xp



Because of the constraints provided by the double Pomeron interaction, glueballs, hybrids, and other states coupling preferentially to gluons, will be produced with much reduced backgrounds compared to standard hadronic production processes. The massive system could form resonances, heavy flavour …

A rich physics program with tagged forward protons in polarized p+p scattering at RHIC

Discovery Potential at EIC

http://belle.kek.jp/belle/talks/moriondQCD10/pakhlov.ppt

Many (>10) states poorly consistent with quark model

State	M (MeV)	Γ (MeV)	J^{PC}	Decay Modes	Production Modes
$Y_s(2175)$	2175 ± 8	58 ± 26	1^{--}	$\phi f_0(980)$	e^+e^- (ISR) $J/\psi \to \eta Y_s(2175)$
$X(3872)$	3871.4 ± 0.6	< 2.3	1^{++}	$\pi^+\pi^- J/\psi$, $\gamma J/\psi, D\bar{D}^*$	$B \to KX(3872)$, $p\bar{p}$
$X(3915)$	3914 ± 4	23 ± 9	$0/2^{++}$	$\omega J/\psi$	$\gamma\gamma \to X(3915)$
$Z(3930)$	3929 ± 5	29 ± 10	2^{++}	$D\bar{D}$	$\gamma\gamma \to Z(3940)$
$X(3940)$	3942 ± 9	37 ± 17	$0^{?+}$	$D\bar{D}^*$ (not $D\bar{D}$ or $\omega J/\psi$)	$e^+e^- \to J/\psi X(3940)$
$Y(3940)$	3943 ± 17	87 ± 34	$?^{?+}$	$\omega J/\psi$ (not $D\bar{D}^*$)	$B \to KY(3940)$
$Y(4008)$	4008^{+82}_{-49}	226^{+97}_{-80}	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^-(ISR)
$X(4160)$	4156 ± 29	139^{+113}_{-65}	$0^{?+}$	$D^*\bar{D}^*$ (not $D\bar{D}$)	$e^+e^- \to J/\psi X(4160)$
$Y(4260)$	4264 ± 12	83 ± 22	1^{--}	$\pi^+\pi^- J/\psi$	e^+e^-(ISR)
$Y(4350)$	4361 ± 13	74 ± 18	1^{--}	$\pi^+\pi^- \psi'$	e^+e^-(ISR)
$X(4630)$	4634^{+9}_{-11}	92^{+41}_{-32}	1^{--}	$\Lambda_c^+\Lambda_c^-$	e^+e^-(ISR)
$Y(4660)$	4664 ± 12	48 ± 15	1^{--}	$\pi^+\pi^- \psi'$	e^+e^-(ISR)
$Z(4050)$	4051^{+24}_{-23}	82^{+51}_{-29}	?	$\pi^\pm \chi_{c1}$	$B \to KZ^\pm(4050)$
$Z(4250)$	4248^{+185}_{-45}	177^{+320}_{-72}	?	$\pi^\pm \chi_{c1}$	$B \to KZ^\pm(4250)$
$Z(4430)$	4433 ± 5	45^{+35}_{-18}	?	$\pi^\pm \psi'$	$B \to KZ^\pm(4430)$
$Y_b(10890)$	$10,890 \pm 3$	55 ± 9	1^{--}	$\pi^+\pi^-\Upsilon(1,2,3S)$	$e^+e^- \to Y_b$

observed last 6 years by B-factories

Heavy Flavor States Discovered by B-factories

Heavy flavor hypernuclei

Predicted to exist (PRL 39, 1506 (1977))

Not produced in pp, ep collisions

Not produced in fixed target experiment.

EIC has enough energy for charm and bottom hypernuclei.

Needs vertex detector at fragmentation region.

With high baryon density, RHIC has the potential for discovering heavy flavor & baryon hybrid states

Summary

• RHIC is an ideal machine for exotic/antimatter production.

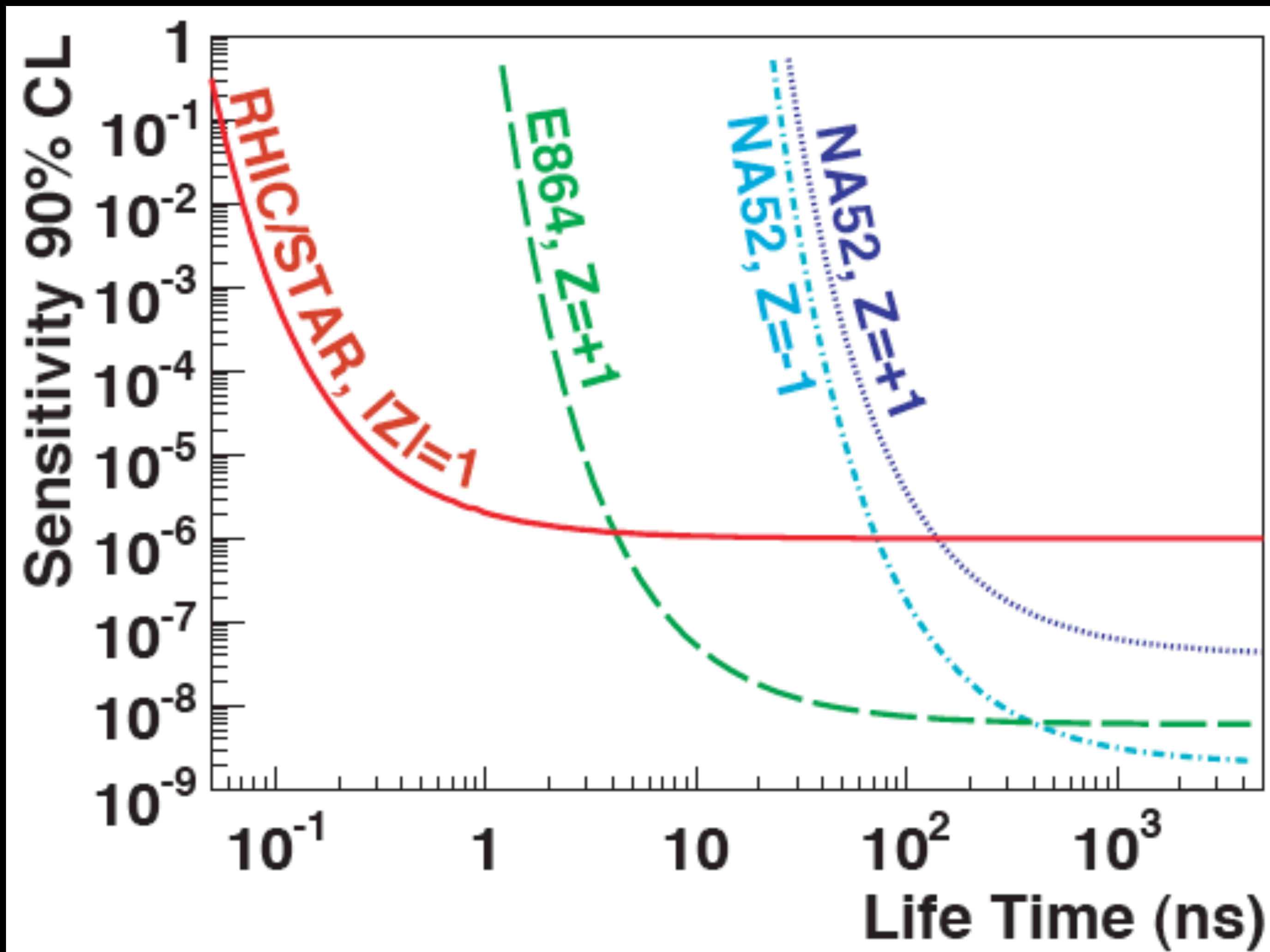
• STAR is in excellent position for exotic/antimatter/ rare-decay search.

• STAR has made important discoveries. With more proposed upgrades (HLT, DAQ10k, phase II pp2pp etc.), STAR will significantly broaden its search range for new/exotic phenomena.

• Together, we can expand RHIC’s research horizon.

Backup Slides

Upper Limit of Strangelet Production in Forward Region



STAR, PRC 76, 011901 (2007)